Erosion of Ceramic Particle Composite Products for Pipe Transportation

Yoshiyasu MORITA, Hisakazu KAWASHIMA and Manabu SEGUCHI¹⁾

Iron & Steel Research Laboratory, Sumitomo Metal Industries, Ltd., Fuso-cho, Amagasaki, Hyogo-ken, 660 Japan.

¹⁾ Sumikin Techno Research, Ltd., Fuso-cho, Amagasaki, Hyogo-ken, 660 Japan.

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The erosion of the metal-ceramic particles dispersion composite materials was experimented for the purpose of improving the erosion resistance of the elbow for the transportation line of solid particles. The composite flat plates were made by casting method adding the alumina particles of 3 mm diameter into each matrix. The effects of the impingement particle and the impingement angle on the erosion of the composite were investigated. It was made clear that the erosion ratio of the composite was decreased to a half of the average value of the matrix only. Then, the improvement of the erosion resistance of the trial composite elbow was confirmed.

KEY WORDS: composite material; ceramics; erosion; maintenance; mechanical testing; wear.

1. Introduction

The equipments in the steel, mining and ceramic industries, etc. have been used under sever operating conditions from the requirement for the size enlargement and the high efficiency. The durability of the equipments is determined by several factors such as fatigue, corrosion, wear, etc.

As for the wear, in the transportation lines of the coal crushing plant or the plant removing the silicon from pig iron, the internal surface of the elbows or the branch joints where the flow of internal fluid changes its direction has been suffered from severe erosion by the impingement of solid particles of the coal or the sintered steel grit in the internal fluid.

The lifetime of the elbow is short compared with that of the straight line pipe, so the high Cr cast iron or the ceramics with a high wear resistance has been used. However, it has not always shown the high erosion resistance against some impingement particle materials or impingement angle. Much investigations on the erosion of the metal or the ceramics itself have been conducted,¹⁻¹¹⁾ but few results have been reported on the erosion of the composite.^{12,13)}

In this paper, the basic erosion properties of the composite by the impingement of solid particles were investigated on the flat plate test specimen whose matrix was strengthened by the dispersion of ceramic particles.¹⁴⁾ And, the erosion resistance of the trial ceramic particle composite elbow was made clear.

2. Test Method

2.1. Test Apparatus

In the test apparatus shown in Fig. 1, the solid particles were acceralated by the air flow of high velocity. The particles injected from the nozzle were impinged on the flat plate with the impingement angle θ , and then carried to the reservoir tank for the fol-

lowing injection from the nozzle. The impingement angle of particles was adjusted by changing the angle of the plate holder for the flat plate test specimen.

In the erosion test of the elbow, the solid particles were injected into the vertical pipe connected to the elbow as shown in Fig. 2.

2.2. Test Specimen

The chemical composition and the Vickers hardness of the tested matrix and ceramic particles are shown in Table 1. These matrixes and their composites with ceramic particles were made by casting. The chemical composition of the matrices A to C was that of the plain cast steel, the plain cast iron and the 27 % Cr cast iron, respectively. The ceramic particle was the alumina particle of 3 mm diameter.

The dimensions of the flat plate specimen was 40 mm in width, 50 mm in length and 10 mm in thickness. The particles were impinged on the casted surface of the specimen. The surface of the composite plate was covered by the matrix, exposing a very small part of the ceramic particles.

The configuration of the composite elbow is shown in Fig. 3. It is a 90° elbow with 25 mm inside

Fig. 1. Test apparatus for flat plate specimens.

Table 1. Chemical composition and Vickers hardness of materials.

Materials		Chemical composition (wt%)										Vickers hardness (HV)	
		C	Si	Mn	P	S	Ni	Cr	Mo	Fe	Al ₂ O ₃		SiO ₂
Matrix	A	0.21	0.45	0.51	0.02	0.02	—	—	—	Bal.	—	—	182
	B	2.80	2.57	0.71	0.02	0.02	—	—	—	Bal.	—	—	261
	C	3.21	1.21	0.69	0.01	0.01	1.03	26.23	0.49	Bal.	—	—	591
Particle		—	—	—	—	—	—	—	—	—	91	7	970

Fig. 2. Test method for elbow specimens.

Fig. 3. Elbow specimen.

diameter, 8 mm wall thickness, and 60 mm radius of curvature. The elbow was made by the lost wax method. The mold was heated up to 1 200°C so that the liquid metal can penetrate into the gap between ceramic particles in the mold. The flange was welded or screwed to the end of the elbow. The volume fraction of the ceramic particles was about 60 % in the composite plate and 58 % in the composite elbow.

The tested impingement solid particles were the silica sand, the steel grit, and the sintered steel grit used to remove the silicone from pig iron. The properties of these particles are shown in Table 2.

2.3. Test Conditions

The erosion test of the flat plate specimen was conducted under the conditions of 7 mm nozzle diameter, 0.294 MPa air pressure, 50 mm distance between the nozzle tip and the plate. The impingement angles were 30°, 45° and 60° considering the impingement angle to the elbow. The area of the oval region on the flat plate test specimen where the particles were impinged was 700, 460 and 370 mm² at the impingement angle 30°, 45° and 60°, respectively. The continuous injection time was 15 min and the eroded

Table 2. Experimental condition and properties of impingement particles.

	Material	Vickers hardness (HV)	Median particle diameter (μm)	Fed weight* (g/min)
a	Silica sand	1 100	0.65	660
b	Sintered steel grit	842	0.20	630
c	Steel grit	790	0.30	1 700

* Air pressure : 0.294 MPa, Nozzle diameter : 7 mm

weight of the plate specimen after each injection was measured. All particles were exchanged after 15 min continuous injection. After the total 60 min injection, the maximum eroded depth of the plate specimen was measured in addition to the eroded weight.

In the erosion test of the elbow, the silica sand was injected into the pipe from 7 mm diameter nozzle at 0.294 MPa air pressure as shown in Fig. 2. The length of a vertical straight pipe was about 9 times of the pipe inside diameter so that the distribution of the impingement particles on the cross section at the inlet of the elbow can be almost uniform. The first continuous injection time was 1 h and the following continuous injection time was 2 h. After each injection, the eroded weight of the elbow specimen was measured and all solid particles was exchanged with new ones. Moreover, the new silica sand was added into the reservoir at every 15 min during the continuous injection to keep the particle size constant.

3. Test Results and Considerations

3.1. Erosion of the Composite Flat Plate

As an example of the erosion test results, the relationships between the eroded weight of the specimen and the injection time of the impingement particles were shown in Figs. 4 to 6. The silica sand, the sintered steel grit and the steel grit were impinged on the flat plate specimen of the matrix A (the matrix A plate) and the flat plate specimen composed of the matrix A and the alumina particles (the composite A plate).

The eroded weight of the matrix A plate increased in proportion to the injection time for all kinds of the impingement particles. The eroded weight of the composite A plate during the first 15 min was comparatively large due to the erosion of the matrix A near the surface of the plate. After alumina particles appeared on the surface about 1 mm in height, the

Fig. 4. Eroded weight of the matrix A and its composite by silica sand.

Fig. 5. Eroded weight of the matrix A and its composite by sintered steel grit.

Fig. 6. Eroded weight of the matrix A and its composite by steel grit.

increasing ratio of the eroded weight with the injection time decreased due to the high erosion resistance of the alumina.

As for the effect of the impingement angle on the erosion, the eroded weight of the matrix A plate increased at the small impingement angle. This result shows that the matrix A is weak for the cutting wear⁽¹¹⁾ at the small impingement angle. On the other hand, the eroded weight of the composite A plate after 60 min increased in order of 60°, 30°, 45° impingement angle, because the increasing ratio of the eroded weight with the injection time at 30° impingement angle decreased after the first 15 min injection. The increase of the eroded weight of the composite plate after 45–60 min injection was almost in proportion to the injection time. Then, it is considered that the relationship between the eroded weight and the impingement angle does not change after 60 min injection. Therefore, the eroded weight ratio and the eroded depth ratio defined by Eqs. (1) and (2) were evaluated by the eroded weight and the eroded depth of the flat plate specimen after 60 min injection.

The eroded weight ratio

$$= \frac{\text{Eroded weight of specimen}}{\text{Total impinged particles' weight}} \quad \text{.....(1)}$$

The eroded depth ratio

$$= \frac{\text{Maximum eroded depth of specimen}}{\text{Total impinged particles' weight}} \quad \text{.....(2)}$$

The effects of the impingement angle on the eroded weight ratio and the eroded depth ratio are shown in Fig. 7. The decrease of the eroded weight of the composite A plate from that of the matrix A plate was large at the small impingement angle 30°. This result shows that the cutting wear resistance of the alumina particles in the composite A plate is higher than that of the matrix A. On the other hand, the eroded depth ratio of the matrix A plate little changed at all the tested impingement angles. This result shows that, at large impingement angle, the depth eroded by the kinematic energy of the impingement

Fig. 7. Effect of the impingement angle on the erosion of the matrix A and its composite.

particles normal to the flat plate specimen increased but that parallel to the flat plate specimen decreased. The eroded depth ratio of the composite A plate decreased at small impingement angle. This result shows that the cutting wear resistance of the composite A plate was increased by the alumina particles at small impingement angle.

The example of the eroded specimen is shown in Fig. 8, which represents that the eroded depth of the composite A plate becomes much lower than that of the matrix A plate due to the alumina particles.

3.2. The Effects of Several Factors on the Erosion

3.2.1. The Erosion of the Matrix

In order to investigate the effect of the matrix material on the erosion of the composite, the effect of the impingement angle on the eroded weight ratio and the eroded depth ratio of the matrix plate after 60 min injection is shown in Figs. 9 to 11 for each impingement particle. The eroded weight ratio of the matrix plate decreased generally in order of the matrix B, A and C. The Vickers hardness of the matrix B is about 1.5 times larger than that of the matrix A as shown in Table 1, but the impact value of the matrix B is about 1/30 times smaller than that of the matrix A as shown in Table 3. Therefore, it is considered

Fig. 8.
Eroded plates by silica sand with 30° impingement angle after 1 h test.

Fig. 9. Effect of target materials on erosion by silica sand.

Fig. 10. Effect of target materials on erosion by sintered steel grit.

Fig. 11. Effect of target materials on erosion by steel grit.

Table 3. Charpy test results.

Specimen		Impact value (J/m ²)
Matrix	A	19.9×10^{-5}
	B	0.60×10^{-5}
	C	0.18×10^{-5}
Composite	A	2.28×10^{-5}
	B	0.11×10^{-5}
	C	0.16×10^{-5}

that the eroded weight ratio of the matrix B plate became larger than that of the matrix A plate due to the impact fracture of the matrix B. The Vickers hardness of the matrix C is larger than not only the matrices A and B but also the sintered steel grit and the steel grit. Therefore, the matrix C plate showed

the high erosion resistance against above impingement particles than the matrices A and B plates did. On the other hand, when the silica sand was impinged at the angle of 45°–60°, the eroded weight ratio of the matrix C plate became larger than that of the matrix A plate as shown in Fig. 9. This result shows that the matrix C plate was eroded by the impact fracture, because the matrix C with small impact strength shown in Table 3 could not resist the kinematic energy of the silica sand with high Vickers hardness at the large impingement angle.

The effect of the matrix material on the eroded depth ratio of the matrix plate was almost the same as that on the eroded weight ratio of the matrix plate. That is, although the eroded depth ratio decreased generally in order of the matrix B, A and C plates, the eroded depth ratio of the matrix C plate by the silica sand at the angle of 45°–60° became larger than that of the matrix A plate as shown in Fig. 9.

3.2.2. Erosion of the Composite

In order to investigate the effect of alumina particles on the improvement of the erosion resistance of the matrix itself, the relationship between the erosion of the matrix plate and that of the composite plate is summarized in Figs. 12 and 13. As shown in Fig. 12, the eroded weight ratio of the composite plate decreased to about 50–25 % of that of the matrix plate in order of the composite A, C and B plates.

As stated in Sec. 3.2.1, the eroded weight ratio of the matrix B plate was the largest, so the erosion resistance of the composite B plate was remarkably increased by the alumina particles compared with another composite plates. The eroded weight ratio of the composite C plate by the silica sand was about 40 % of that of the matrix C plate. The erosion of the composite C plate by another impingement particles was not large enough to show the effect of the alumina particles, because the erosion of the matrix C plate itself was very small. The decrease of the eroded weight ratio of the composite A plate from that of the matrix A plate at the impingement angle 30° was almost the same as that of the composite C plate. The decrease of the eroded weight ratio of the composite A plate from that of the matrix A plate at the impingement angle 45°–60° was smaller than that at the impingement angle 30°.

Fig. 13 shows the comparison of the eroded depth ratio of the matrix plate with that of the composite plate. The decrease of the eroded depth ratio of the composite plate from that of the matrix plate decreased in order of the composite A, C and B plates like the results of the eroded weight ratio. The decrease of the eroded depth ratio of the composite A plate from that of the matrix A plate at the impingement angle 45°–60° was smaller than that at the angle 30°. The reason of the above result is investigated in Sec. 3.2.4.

3.2.3. The Effect of the Impingement Particles

From the results in Figs. 9 to 11, both the eroded weight ratio and the eroded depth ratio of the matrix plate and the composite plate increased in order of

Fig. 12. Relationship between the eroded weight ratio of the matrix and that of the composite.

Fig. 13. Relationship between the eroded depth ratio of the matrix and that of the composite.

the steel grit, the sintered steel grit and the silica sand. It can be said that the erosion is much affected by the Vickers hardness of impingement particles within the range of particle diameters shown in Table 1.

3.2.4. The Effect of the Impingement Angle

As shown in Figs. 9 to 11, the eroded weight ratio of the matrix plate increased in the matrices A and B and decreased in the matrix C with decrease of the impingement angle of the particles. This result shows that the cutting resistance of the matrix A plate at small angle is small due to its low Vickers hardness, and that the deformation resistance of the matrix C plate at large angle is small due to its small impact strength in spite of its high Vickers hardness. The eroded weight ratio of the matrix B plate was larger than that of the matrices A and C plates due to both its low Vickers hardness and small impact strength.

The eroded depth ratios of the matrices B and C, plates were large at the angle 45°–60°, although that of the matrix A plate little changed with the angle. From this result, it is considered that the eroded depth ratios of the matrices B and C plates with small impact strength were dominated mainly by the kinematic energy of the impingement particles normal to the specimen. On the other hand, the eroded depth

ratio of the matrix A plate at large impingement angle did not decrease due to its large impact strength.

As for the eroded weight ratios of the composite plates, the decrease of the eroded weight ratios of the composite A and B plates from those of the matrices A and B plates with low cutting resistance were large at small angle due to the high erosion resistance of the alumina particles. The decrease of the eroded weight ratio of the composite C plate from that of the matrix C plate at small impingement angle was smaller than those of the composite A and B plates due to the high cutting resistance of the matrix C.

The eroded depth ratios of the composite B and C plates became smaller at small angle like the results of the matrices B and C plates. The decrease of the eroded depth ratio of the composite A plate from that of the matrix A plate was large at the angle 30° as stated in Sec. 3.2.2. This result shows that, at small impingement angle 30° , the erosion of the matrix A plate is caused mainly by the cutting wear due to the large kinematic energy of impingement particles parallel to the surface of the plate. When the silica sand was impinged to the test plate at 30° impingement angle, the maximum eroded depth ratio of the matrix A plate was 1.39×10^{-4} mm/g and that of the composite A plate was decreased to 0.49×10^{-4} mm/g by the high cutting wear resistance of the alumina particles.

On the other hand, at large impingement angle 60° , the erosion of the matrix A plate is dominated by the deformation wear due to the large kinematic energy of impingement particles normal to the surface of the plate. At the impingement of the silica sand on the matrix A plate at 60° impingement angle, the maximum eroded depth ratio was 1.34×10^{-4} mm/g which was almost as large as 1.39×10^{-4} mm/g at 30° impingement angle. This result shows that the deformation wear resistance of the matrix A plate is as large as its cutting wear resistance, which is different from the results of the matrices B and C plates. On the other hand, the maximum eroded depth ratio of the composite A plate at 60° impingement angle decreased by a little amount from 1.34×10^{-4} mm/g of the matrix plate to 1.12×10^{-4} mm/g, because the deformation resistance of the matrix A is large and that of the alumina particles is small.

3.2.5. Eroded Weight Ratio and Eroded Depth Ratio

The relationship between the eroded weight ratio and the eroded depth ratio of the matrix plate and that of the composite plate are shown in Figs. 14 and 15, respectively. In Fig. 14, with increase of the eroded weight ratio, the eroded depth ratio of the matrix A plate increased a little and that of the matrix C plate increased almost in proportion to its eroded weight ratio. On the other hand, the eroded depth ratio of the matrix B plate decreased with increase of the eroded weight ratio.

In Fig. 15, the eroded depth ratio of the composite C plate increased almost in proportion to its eroded weight ratio like the result of the matrix C plate. On

Fig. 14. Relationship between the eroded weight ratio and the eroded depth ratio of the matrix.

Fig. 15. Relationship between the eroded weight ratio and the eroded depth ratio of the composite.

the other hand, the eroded weight ratios of the composite A and B plates increased a little with increase of their eroded weight ratios, which is different from the results of the matrices A and B plates.

3.3. Erosion of the Composite Elbow

Based on the test results of the matrix plate and the composite plate, the composite elbow was made of the alumina particles and the matrix A which has the good erosion resistance, high impact strength and cheap cost. The erosion of the composite elbow by the impingement of the silica sand with the high Vickers hardness was tested and compared with the erosion of the casted elbows of the matrices A and C. The elbow of the matrix A was eroded to the outside surface of the wall in 8 mm thickness after 21.7 h impingement test as shown in Fig. 16. The total injected weight of the silica sand was 860 kg. On the other hand, the maximum eroded depth in the

Fig. 16. Erosion of elbows.

thickness direction after 21.7 h in the elbows of the matrix C and the composite A was 7.5 and 4.5 mm, respectively. The relationship between the maximum eroded depth of the elbow of the matrix A and that of the composite A is shown in Fig. 12 by the symbol ∇ . It is confirmed from this figure that the erosion resistance of the composite elbow is increased by the alumina particles as well as that of the composite plate.

4. Conclusions

The erosion properties of the composite made of the matrix and the alumina particles were tested by the impingement of the solid particles. The results are summarized as follows.

(1) The eroded weight ratio and the eroded depth ratio of the matrix increased generally in order of the 27 % Cr cast iron, the plain cast steel and the plain cast iron. However, when the silica sand was impinged at the angle 45° – 60° , the erosion of the 27 % Cr cast iron was larger than that of the plain cast iron.

(2) By composing the matrix and the alumina particles, the eroded weight ratio and the eroded depth ratio of the composite decreased to 25–50 % and 25–80 % of the matrix, respectively.

(3) The eroded weight ratio and the eroded depth ratio of the matrix and the composite increased with the Vickers hardness of the impingement particles.

(4) With increase of the impingement angle of the particles, the eroded weight ratio of the matrix decreased in the plain cast steel and the plain cast iron,

and increased in the 27 % Cr cast iron. On the other hand, with increase of the impingement angle, the eroded depth ratio of the plain cast steel little changed, although those of the plain cast iron and the 27 % Cr cast steel increased.

(5) The eroded weight ratio of the composite is not so much affected by the impingement angle of particles. On the other hand, the eroded depth ratio of the composite decreased at small impingement angle.

(6) The erosion resistance of the alumina particles composite elbow was increased as much as the composite flat plate.

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REFERENCES

- 1) J.G.A. Bitter: *Wear*, **6** (1963), 5.
- 2) J.G.A. Bitter: *Wear*, **6** (1963), 169.
- 3) J. H. Neilson and A. Gilchrist: *Wear*, **11** (1968), 111.
- 4) G. L. Sheldon and A. Kanhere: *Wear*, **21** (1972), 195.
- 5) J. L. Routbort, R. O. Scattergood and E. W. Kay: *J. Am. Ceram. Soc.*, **63** (1980), 635.
- 6) H. Honma and K. Ito: *Trans. Jpn. Soc. Mech. Eng. (A)*, **50** (1984), 966.
- 7) S. Wada and N. Watanabe: *J. Ceram. Soc. Jpn.*, **94** (1986), 1157.
- 8) S. Wada and N. Watanabe: *J. Ceram. Soc. Jpn.*, **95** (1987), 573.
- 9) S. Wada and N. Watanabe: *J. Ceram. Soc. Jpn.*, **95** (1987), 976.
- 10) K. Shimoda and H. Hozyo: *Trans. Jpn. Soc. Mech. Eng. (A)*, **54** (1988), 1937.
- 11) K. Hashimoto: *Huntai-Mamo no Taisaku*, Nikkan Kogyo Shinbunsha, Tokyo, (1981), 180.
- 12) K. Hashizume and K. Sakai: *Komatsu-Giho*, **27** (1981), 8.
- 13) S. Wada, N. Watanabe and T. Tani: *J. Ceram. Soc. Jpn.*, **96** (1988), 111.
- 14) Y. Morita, K. Okamura, H. Kawashima and M. Seguchi: *Tetsu-to-Hagané*, **75** (1989), 1596.

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